GEORGIA FOREST RESEARCH PAPER

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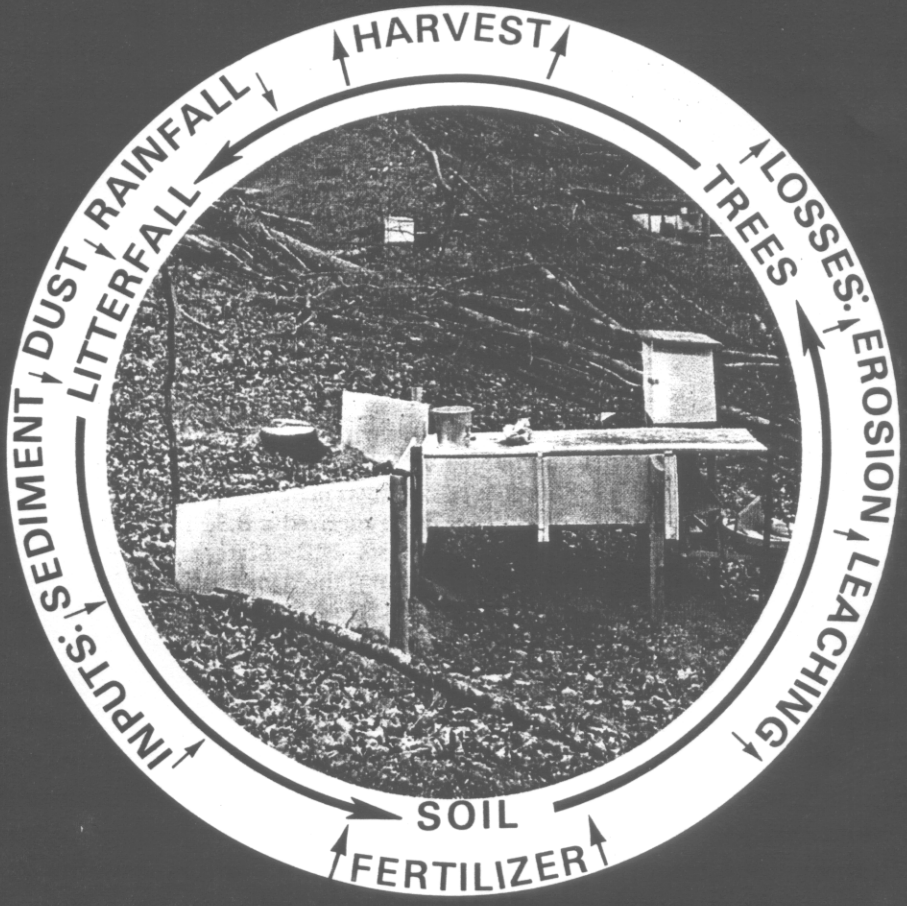

WOODY BIOMASS HARVESTING AND SITE PRODUCTIVITY

Ongoing Research in Georgia and Adjacent States

by W. Henry McNab and James W. McMinn

RESEARCH DIVISION

GEORGIA FORESTRY COMMISSION

AUTHORS

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COVER

Instrumentation to examine the nutrient status of a cleared forest site, Oak Ridge National Laboratory. The diagram depicts three phases of the productivity question: inputs, nutrient cycling, and outputs. Natural processes are shown in black. Potential inputs and outputs of management are shown in green and red, respectively.

WOODY BIOMASS HARVESTING AND SITE PRODUCTIVITY

ONGOING RESEARCH IN GEORGIA AND ADJACENT STATES

By

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INTRODUCTION

Biomass, until relatively recently, has been the main source of energy, worldwide. In developing countries, it continues to be important and, in many areas, increasing dependence on biomass for firewood and production of charcoal is accelerating deforestation. Potential oil shortages in developed countries are creating new interest in biomass as a renewable source of energy. Forest industries in the South are utilizing more biomass for energy as fossil fuel costs rise and supplies become less dependable.

Georgia and the Southeast as a whole are ideally suited for the expanded use of forest biomass for energy. The climate, with its long growing season and relatively mild winter, is suitable. Annual rainfall ranges from about 40 to 60 inches and is distributed fairly evenly throughout the year. Soils are generally fertile, easily worked, and stable for most forestry related activities, with the exception of the mountains, where steep terrain is a limiting factor.

Pines constitute the single most common group of species in Georgia, and have the greatest commercial value. Hardwoods become more prevalent from the middle of the state northward, achieving full dominance in the mountains, where, except for certain species, they may be of such low quality that they have little commercial value.

Greater use of biomass is desirable because it is available, renewable, and is a means of increasing utilization of unmerchantable hardwoods. Typically, in mixed pine-hardwood stands, low-quality large trees, as well as smaller understory trees, remain on the site to be disposed of by site preparation before reforestation. However, disposal is costly, may reduce the area available for planting, and can cause soil erosion or heterogeneous distribution of soil organic material. If prescribed burning is necessary, residue disposal contributes to air pollution.

Recent innovations in equipment now make it economically feasible to harvest trees once considered too small or scattered to be cut. Stationary whole-tree chippers are manufactured in a range of sizes and, by mid-1981, at least 29 were being used on logging operations throughout Georgia. Prototype mobile chippers that cut swaths, eliminating the need for individual tree felling and skidding, are also being tested. Such equipment increases the efficiency of harvesting on marginal sites with low stocking.

However, there is concern that more intensive biomass harvesting may lower site productivity by removing vital nutrients normally left in logging debris. Accelerated soil erosion and compaction also may result from removing protective cover and from increasing disturbance by harvest machinery.

Comparisons of biomass harvesting are being made to farming, where fertilization is needed to replace nutrients removed by annual crop harvesting. If nutrients are depleted from forest sites, is increased utilization of biomass profitable over the long term? Are there certain sites that can safely yield the additional harvest? How frequently can a harvest be made with ac-

ceptable nutrient depletion? Land managers and forestry consultants are increasingly asking these questions in response to the Georgia Forestry Commission's wood energy program that demonstrates the economic potential of greater utilization of wood as an energy resource in the state (1).

Answers to such questions are not yet definitive because considerable time is needed to obtain them. A site under study must be sampled for baseline data before the timber harvest, then monitored for at least 5 years to determine probable trends in site and vegetation recovery. Frequently more than 10 years are needed.

However, to examine tentative answers, an informal conference sponsored by the U.S. Forest Service and the Georgia Forestry Commission was held for researchers from Georgia and adjacent states.[1/] The goal of the conference was to determine the state of knowledge about nutrient losses resulting from intensive biomass harvesting. The conference revealed that considerable research is being done but that there are few conclusive answers immediately available because of the complexity of the subject.

Conference participants supported the idea of a directory of ongoing research. The purpose is to identify research sites and scientists where natural resource managers may seek the best current data and informed judgment on mitigating impacts of intensive biomass harvesting.

This report is a result of this recommendation. No literature is reviewed because this is being done as part of a cooperative study supported by the Georgia Forestry Commission (2). Our report is concerned with identifying ongoing research and presenting results from this work. The manager is encouraged to consult the researcher for published information as it becomes available.

PRINCIPAL PHYSIOGRAPHIC REGIONS IN GEORGIA

Both climate and soil are important influences affecting site productivity. However, with the exception of localized high rainfall areas in the mountains, precipitation is relatively uniform across the state, averaging from 40 to 60 inches annually. The growing season is more variable, ranging from about 175 frost free days at higher elevations in the mountains, to 300 days near the coast. Topography and soils are even more variable ranging from nearly flat and sandy near the coast to steep and rocky in the mountains. All of these factors only affect species composition and physical properties of the site, but also mechanized harvest operations. Results from one region may not, therefore, apply to another, so research is necessary at a number of locations.

Georgia can be divided into four broad regions with different characteristic topographic features, soils, and forests (3). These physiographic regions are shown in Figure 1, and descriptions follow.

COASTAL PLAINS

For convenience in describing this 23-million-acre region, the soils and forests of the Coastal Plain are subdivided into two subregions, the Lower and Upper Coastal Plains, separated by the dotted line in Figure 1.

Lower Coastal Plains (Flatwoods)

As the name "flatwoods" implies, topography of this subregion is almost level. Elevations range from sea level to about 300 feet above sea level. The sandy soils were developed from marine deposits and generally have high water tables. Most soils are low in organic material with shallow hardpans resulting in poor internal drainage. Runoff is slow and often flows into swamps characterized by the dominance of gum and cypress. The major timber species of the flatwoods are slash and longleaf pines which are managed in even-aged stands, often on intensively prepared sites. Hardwoods typically form a smaller part of the timber resource and are mostly concentrated along river flood plains.

Upper Coastal Plains

Much of Georgia's agriculture is concentrated within this subregion. Topography is nearly level to gently rolling and erosion is not a major problem. Soils are predominantly sandy near the surface, as in the flatwoods, but contain a greater amount of fine-textured material which helps retain water and nutrients. Surface and internal drainage are generally good, and are excessive in the deep sands of the Fall Line Sandhills bordering the Piedmont. Slash pine is the principal timber species in this subregion. Hardwoods are present in the pine stands, particularly in the western part of the Upper Coastal Plains, but most of them are not cut except perhaps locally for firewood. Hardwood invasion in managed pine stands is not a major problem.

PIEDMONT

The lower boundary of the Piedmont in Georgia is along a line defined by Augusta, Macon, and Columbus. Most of the 10.6 million acres in this region have soils that are higher in clay content than those of the Coastal Plains and underlain by acid crystalline and metamorphic rock. Since the terrain of this physiographic region is gently rolling hills, most cleared soils are susceptible to erosion. Most of this area was cleared for agriculture at least once, especially for cotton during the 1800's. Gully erosion on much of the acreage, together with boll weevil infestation, forced agricultural abandonment and the land reverted to second-growth pine-hardwood forests. Loblolly pine is the principal commercial species, but forests contain a higher proportion of small, low-quality and generally unmerchantable hardwoods, including dogwood, sweetgum, oaks, and hickories. Forest management is not as intensive as in the Coastal Plains because of more variable topography. Ingrowth of low-value species requires intensive site preparation for optimum pine production, but on many cutover sites, regeneration depends on natural seedfall. The potential for greater biomass utilization and new markets for whole-tree fuel chips is particularly high in this region because of the large quantity of low-value hardwoods.

RIDGE AND VALLEY

Cedartown, Cartersville, and Chatsworth in the northwestern corner of Georgia mark a rough boundary between this region and the Piedmont and the Blue Ridge. Topography in this 1.8-million-acre region consists of parallel, continuous broad valleys separated by moderately steep slopes and relatively flat ridges. Much of the soil has developed from limestones, sandstone, and shales, and in the valleys, is high in fertility. Most areas of good soils are used for agriculture. Forested sites are dominated by hardwoods with admixtures of pines. Localized areas of redcedar are characteristic of this region. The steep slopes provide good drainage but are subject to erosion and provide difficult access for timber management operations.

[1/] Site Effects from Intensive Utilization of Forest Biomass: September 20, 1980, Forestry Sciences Laboratory, Athens, Georgia.

Figure 1. --Physiographic provinces of Georgia and the location of research sites.

BLUE RIDGE

Only a small part of this 2-million-acre province, bordered by the cities of Jasper, Dahlonega, and Clarkesville, extends into Georgia. Topography in the Blue Ridge Mountains is the highest and most rugged in the state, ranging from steep, sharp-crested ridges to narrow valleys. Elevations range from 700 feet along the foothills to almost 5,000 feet near the North Carolina state line. The rocky, clay soils are typically underlain by parent rock very near the surface. Severe sheet erosion can occur where agriculture is practiced on the shallow soils of slopes and ridgetops. Forests are mostly hardwoods, with yellow-poplar and other soft hardwoods in coves, and oaks and hickories on middle and upper slopes. Pine stands may be present, which developed following a disturbance. In places, pitch and Table Mountain pines dominate the dry, infertile ridgetops. Logging is expensive and stand management is difficult because of the steep terrain. Often only a small part of the total wood resources can be economically utilized.

GENERAL DESCRIPTION OF RESEARCH

Research on impacts of intensive biomass harvesting is being conducted at seven sites in Georgia and adjacent states, in each of the four major physiographic provinces. The research at each site is described in general terms to allow the reader to compare his conditions with those under study.

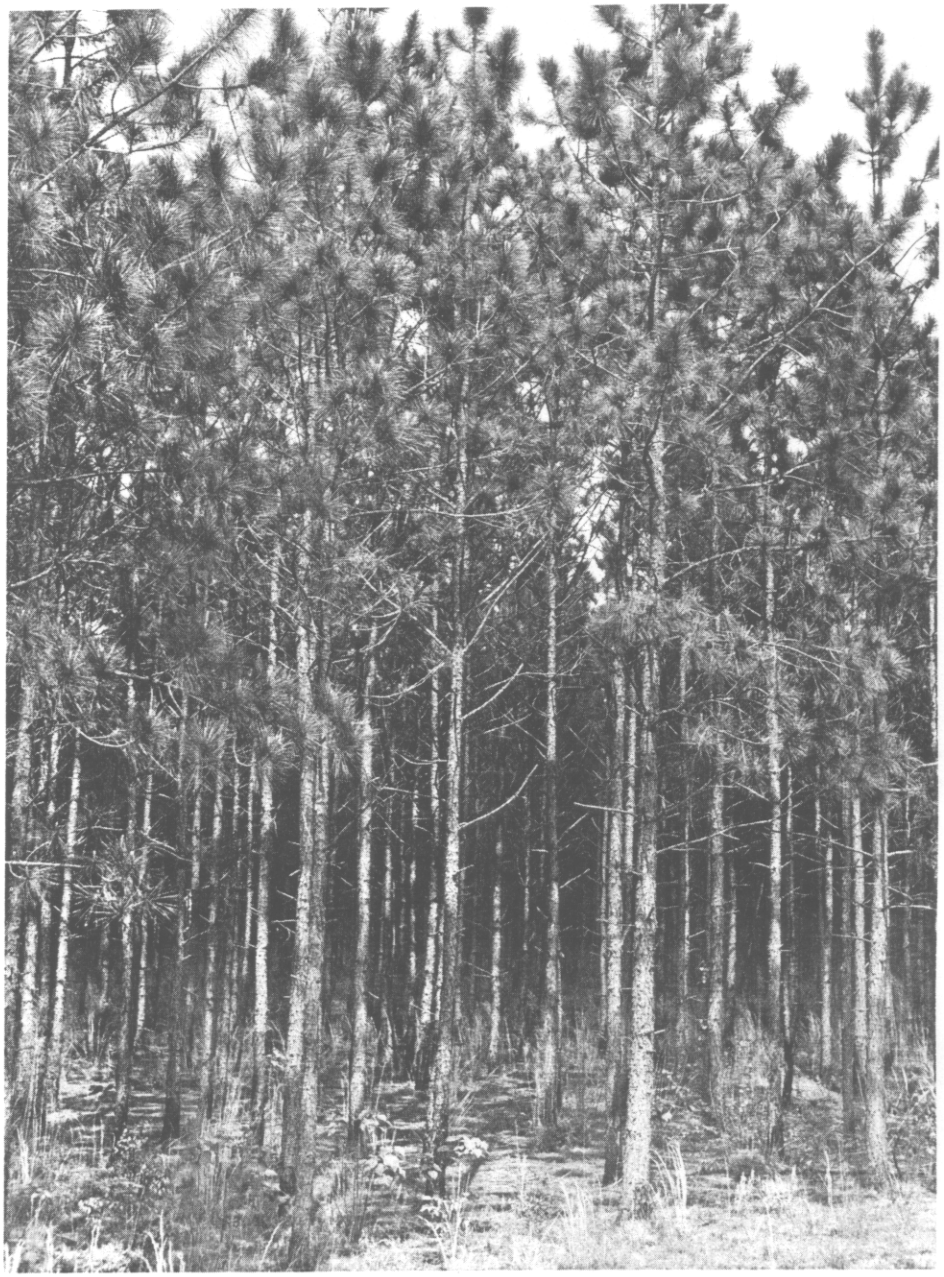

Figure 2. Slash pine plantation, Dooly County, Georgia.

COASTAL PLAINS

Georgia (Site A)

Location: Dooly County, GA, 12 miles north of Cordele.
Plot size: Various, from 0.02 to 5.0 acres.
Elevation: 200 feet.
Aspect: None
Slope: Level to undulating.
Slope position: None.
Soils: Sandy
Principal soil series: Gilead
Forest type: Slash pine plantation (Figure 2).
Age of dominants: Variable, 1 to 47 years depending on plot treatment.
Site index: 60 to 70 feet for slash pine at 25 years.
Pretreatment basal area: 150 ft^2/acre.
Treatment description: Stand rotations of 20, 25, 35, or 50 years will be studied. Nutrient depletion will be estimated for the rotations. Depending on length of rotation, stands on some plots have been harvested, site prepared, and regenerated with planted slash pine.
Study duration: Continuing.
Principal investigators: Wayne T. Swank, Plant Ecologist, Southeastern Forest Experiment Station, Coweeta Hydrological Laboratory, Rt. 1, Box 216, Otto, NC 28763; Jack B. Waide, Ecologist, Environmental Science Division, X-10, Bldg. 1505, Oak Ridge National Laboratory, Oak Ridge, TN 37830; and Earle P. Jones, Research Forester, Southeastern Forest Experiment Station, Macon, GA 31208.

Alabama (Site B)

Location: Lee County, AL, Auburn University Forestry Department woodlot, Auburn University campus.
Plot size: 0.125 acre, complete block experimental design with 3 blocks and 3 plots per block.
Elevation: 640 feet.
Aspect: Northeast.
Slope: 0 to 10 percent ranging from level to moderate.
Slope position: Upper to middle.

Soils: Droughty sands, eroded farmland before afforestation.

Principal soil series: Blanton loamy sand.

Forest type: Half of study area is a slash-loblolly pine plantation, the other half is a shortleaf pine plantation (Figure 3).

Age of dominants: 53 years.

Site index: 80 feet for slash-loblolly, 45 feet for shortleaf, both at 50 years.

Pretreatment basal area: pine, 58 $ft.^2$/acre; hardwoods, 14 ft^2/acre; shrubs, 2 ft^2/acre.

Treatment description: April 1980: Complete aboveground biomass harvested with Nicholson-Koch Mobile Chip Harvestor on 2 plots of each block. June 1980: Tordon 10K herbicide broadcast at rate of 50 lb/acre on 1 plot of each block to control sprouting. February 1981: Planted to loblolly pine spaced at 8 x 8 feet.

Study duration: 3 years.

Principal investigators: James H. Miller, Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, G. W. Andrews Forestry Sciences Laboratory, Auburn University, Auburn, AL, 36849.

Figure 3. --Slash-loblolly pine plantation, Auburn, Alabama.

Florida (Site C)

Location: Bradford County, FL, 6 miles west of Starke.

Plot size: Watershed (WS) No. 1 = 158 acres, No. 2 = 119 acres, No. 3 = 339 acres, No. 4 = 9 acres, No. 5 = 11 acres.

Elevation: 145 feet.

Aspect: None, level terrain.

Slope: 0 to 0.1 percent.

Slope position: None.

Soils: Sandy, 1.5 to 7 feet deep, underlain by clay, poorly drained.

Principal soil series: Stilson, Mascotte, Surrency.

Forest type: Slash and longleaf pine on better drained sites to cypress on poorly drained areas in ponds (Figure 4).

Age of dominants: 25 years.

Site index: 61 feet (at 25 years reference age).

Pretreatment basal area: 71 ft^2/acre.

Treatment description: (a) WS No.1--tree-length logged with site preparation of burning, windrowing, and bedding, planted to slash pine spaced at 6 x 12 feet; (b) WS No. 2--shortwood pulpwood harvest followed by site preparation of double chopping and bedding, planted to slash pine spaced at 6 x 12 feet; (c) WS No. 3--Control, no biomass harvest; (d) WS No. 4--whole-tree harvest with site preparation of chipping, burning and bedding then planted to slash pine spaced at 6 x 12 feet; (e) WS No. 5--whole-tree harvesting and stump removal with site preparation of chopping, windrowing, burning, and furrowing, planted to *Eucalyptus viminalis* spaced at 3 x 6 feet.

Study duration: Continuing.

Principal investigators: Hans Riekerk, Assistant Professor, School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

PIEDMONT

Georgia (Site D)

Location: Dawson County, GA, 7 miles south-southwest of Dawsonville.

Plot size: 1-acre logging plots.

Elevation: 1,300 feet.

Aspect: None.

Slope: Moderate, 5 to 15 percent.

Slope position: Ridgetops, abandoned agricultural land.

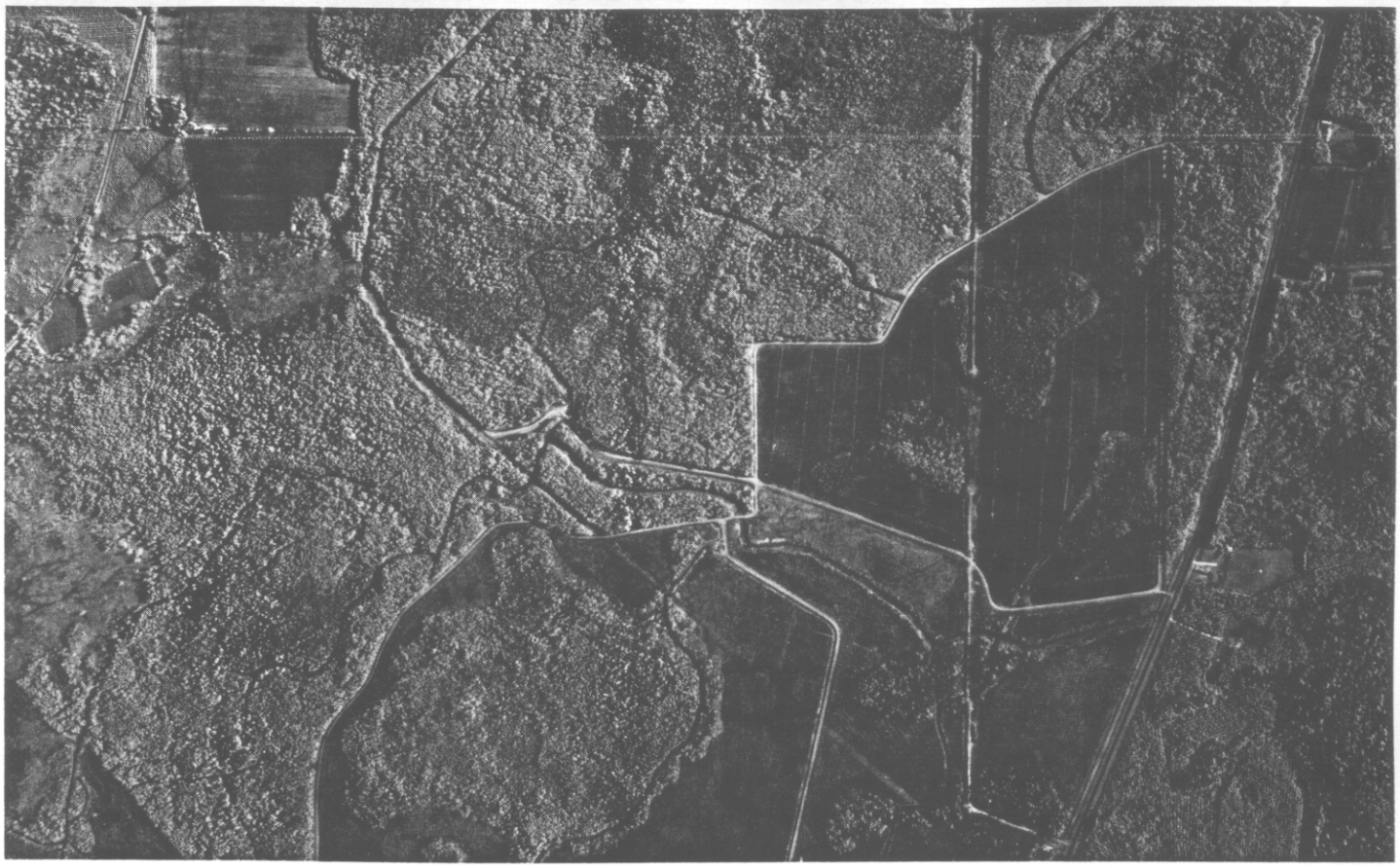

Figure 4. --Aerial view of flatwoods vegetation on experimental watersheds, Bradford County, Florida.

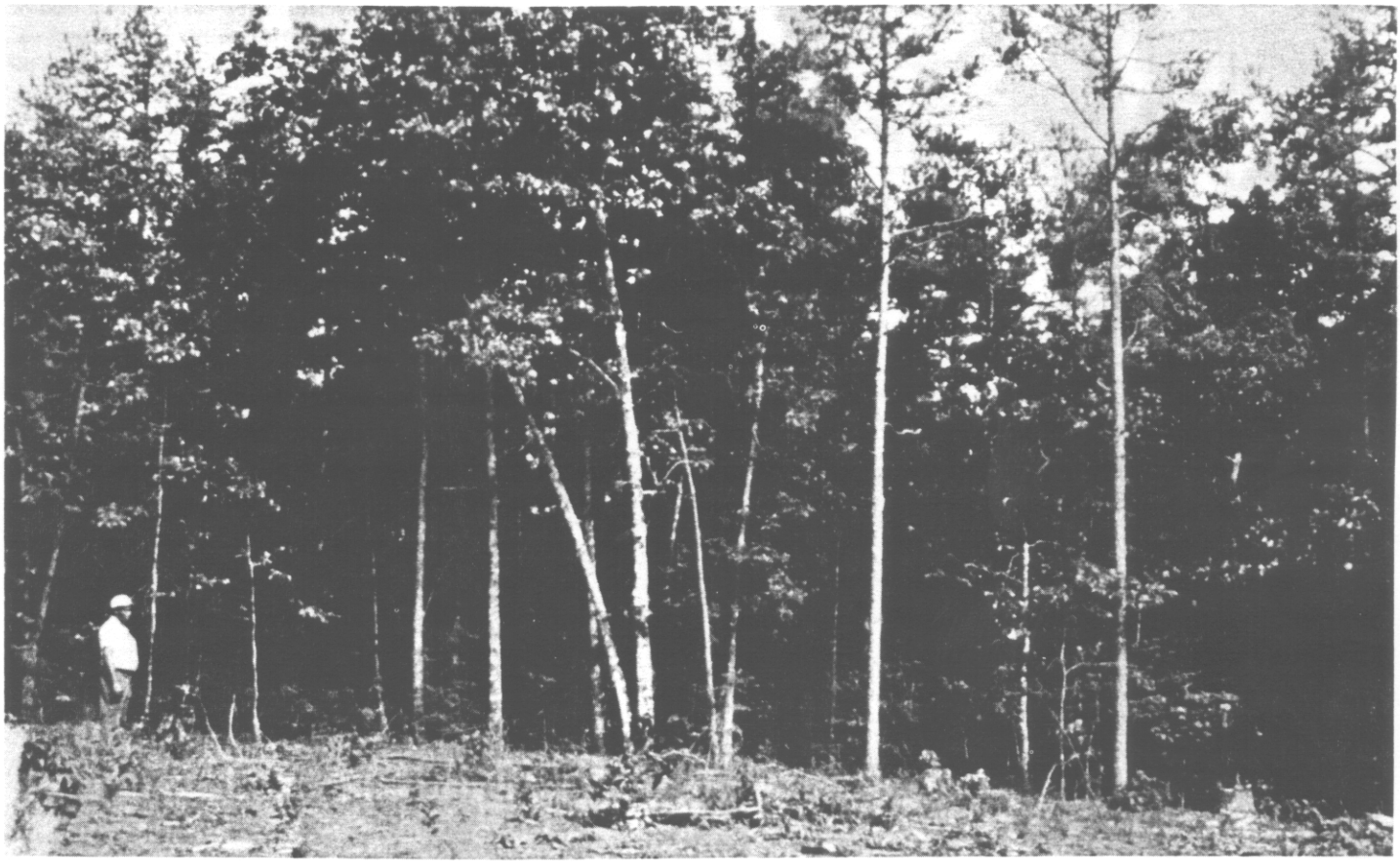

Figure 5. --Mixed oak-pine stand in Dawson Forest, Georgia.

Soils: Fine sandy loam.
Principal soil series: Fannin.
Forest type: Upland oaks-pine (Figure 5).
Age of dominants: Not available.
Site Index: Not available.
Pretreatment basal area: Pine, 26 ft^2/acre; hardwoods, 77 ft^2/acre.
Treatment description: January 1980 and June 1980, whole-tree harvesting of all woody biomass down to (a) 1-inch diameter limit and (b) 4-inch diameter limit.
Study duration: 5 years.
Principal investigators: James W. McMinn, Research Forester, USDA Forest Service, Carlton Street, Athens, GA 30602; and Wade L. Nutter, Associate Professor, School of Forest Resources, University of Georgia, Athens, GA 30602.

South Carolina (Site E)

Location: Oconee County, SC, 5 miles south of Clemson.
Plot size: Watersheds are 3.1, 2.7, and 5.4 acres.
Elevation: 800 feet.
Aspect: Southwest.
Slope: Moderate.
Slope position: Middle to upper.
Soils: Sandy loams, eroded to clay subsoils in places.
Principal soil series: Cecil-Madison.
Forest type: Loblolly pine plantation (Figure 6).
Age of dominants: 40 years.
Site index: 75 feet for loblolly at 50 years.
Pretreatment basal area: 80 ft^2/acre of pine.
Treatment description: December 1979-January 1980: (a) conventional clearcutting with tops left on site; (b) whole tree harvest, logging residue removed; (c) control, no harvest.
Study duration: 3 to 5 years.
Principal investigators: David H. Van Lear, Professor, Department of Forestry, Clemson University, Clemson, SC 29631.

RIDGE AND VALLEY

Tennessee (Site F)

Location: Roane County, 7 miles southwest of Oak Ridge, TN.
Plot size: Watersheds are 0.6, 0.9, 1.1, and 1.3 acres.
Elevation: 900 feet.
Aspect: Various, primarily north and west.

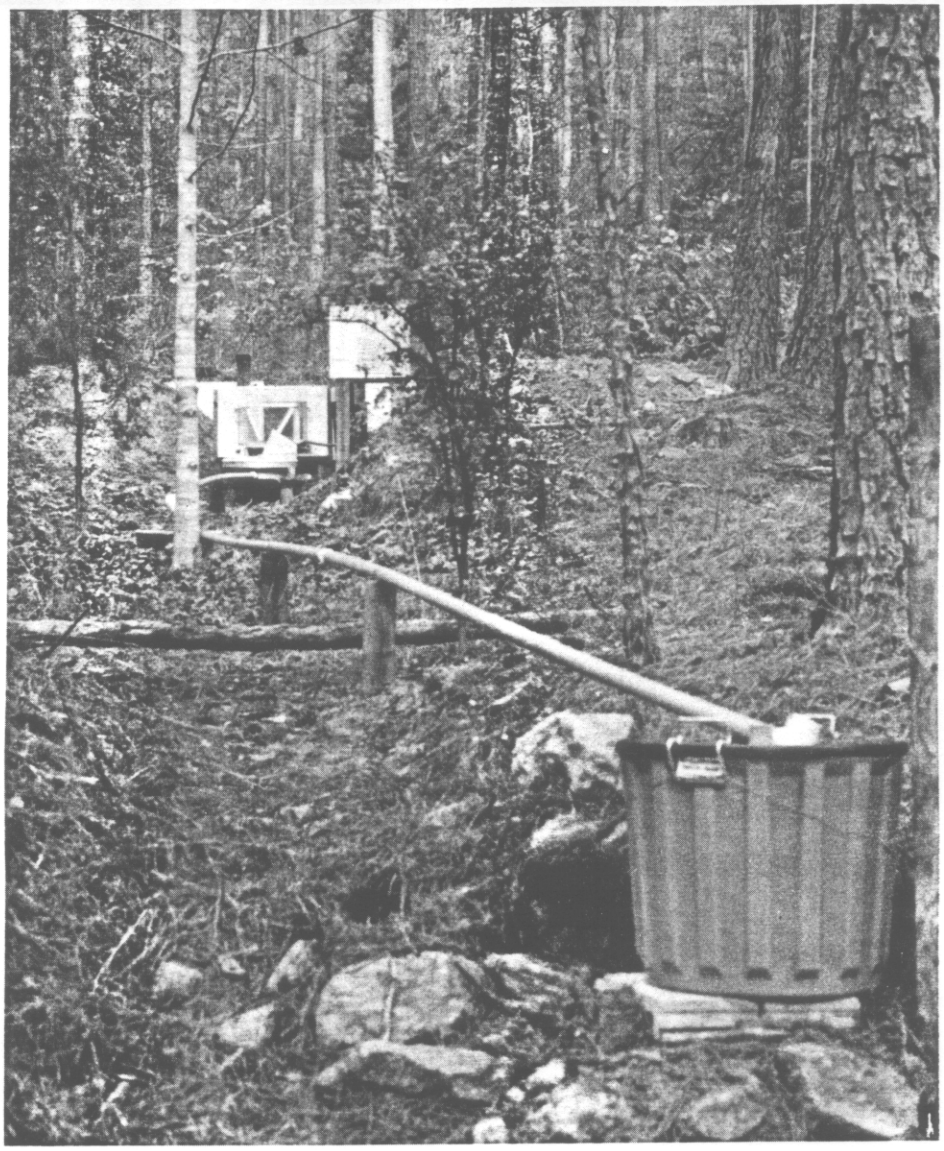

Figure 6. --Loblolly pine plantation, Clemson, South Carolina.

Figure 7. --Upland oak stand at Oak Ridge National Laboratory, Tennessee.

Slope: Moderate to steep, 5 to 45 percent.
Slope position: Upper to middle.
Soils: Cherty silt loam-eroded.
Principal soil series: Minvale, Dunmore, Fullerton.
Forest type: Second-growth upland oak-hickory (Figure 7).
Age of dominants: 50 to 150 years.
Site index: 60 to 70 based on oaks.
Pretreatment basal area: 49 ft^2/acre.
Treatment description: (a) saw logs only removed in conventional harvest with top wood remaining on site, (b) all above-stump material removed along with conventional harvest, and (c) control, no timber harvest.
Study duration: Continuing.
Principal investigators: Darrell C. West, Environmental Science Division, X-10, Bldg. 1505, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

BLUE RIDGE

North Carolina (Site G)

Location: Macon County, NC, 9 miles south of Franklin.
Plot size: Variables, from 0.02 to 0.2 acres; watersheds range from 23 to 150 acres.
Elevation: 2,250 to 5,250 feet.
Aspect: Mainly south and north.
Slope: Average 50 percent.
Slope position: All positions, ridgetop to stream bottom.
Soils: Residual loamy clay to clay loam.
Principal soil series: Chandler, Porters, Saluda.

Forest type: Mixed hardwood, hardwood-pitch pine, white pine (Figure 8).

Age of dominants: 80 to 150 years.

Site index: Not available.

Pretreatment basal area: 120 ft^2/acre.

Treatment description: (a) conversion from hardwood to pine in 1954-55, (b) clearcuts beginning 1939, (c) commercial clearcut and cable logging in 1977, (d) clearcut, cable logging and residue removal in 1980, (e) and old field to forest succession in 1967.

Study duration: Continuing.

Principal investigators: Wayne T. Swank, Plant Ecologist, Southeastern Forest Experiment Station, Coweeta Hydrologic Laboratory, Route 1, Box 216, Otto, NC 28763; and Jack B. Waide, Ecologist, Environmental Science Division, X-10, Bldg. 1505, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

TECHNICAL RESEARCH DESCRIPTION

For all sites, the same overall objective

Figure 8. --Oak-hickory stand at Coweeta Hydrolic Laboratory, North Carolina.

Parameters	Coastal Plains			Piedmont		Ridge & Valley	Blue Ridge
	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Research Approach							
Nutrient budget	X	X	X	X	X	X	X
Nutrient cycling	X	–	–	–	X	X	X
Nutrients studied							
Macro elements	X	X	X	X	X	X	X
Micro elements	–	X	–	X	–	–	X
Others	–	–	–	X	–	–	X
Inputs							
N-fixation	X	–	–	–	X	–	X
Precipitation	–	X	X	–	X	X	X
Fertilization	–	–	X	–	–	–	–
Other	–	–	–	–	–	–	X
Outputs							
Total biomass	X	–	X	X	X	X	X
Biomass harvested	X	X	X	X	X	X	X
Leaching	–	X	X	–	X	X	X
Stream flow	–	–	X	–	X	X	X
CO_2	–	–	X	–	X	X	X
Other	X	–	X	–	X	–	X
Soil Properties							
Compaction	X	X	X	–	–	–	–
Erosion	–	–	X	–	X	X	–
Nutrients	X	X	X	X	X	X	X
Organic matter	X	X	X	X	X	X	X
Disturbance	–	X	–	X	–	–	X
Unpublished reports Available	–	X	X	–	–	X	–

Table 1.-- Summary of parameters studied at research sites in various physiographic provinces to evaluate effects of intensive harvest of forest biomass on site productivity.

is to determine the effects of intensive biomass harvest on forest productivity. However, other objectives may differ depending on the time, equipment, personnel, and financial resources available. The types of data being collected are summarized in Table 1.

PUBLICATIONS AVAILABLE

The following list of articles reporting findings is current as of this printing. However, since new information and unpublished reports may become available at any time, the individual researcher should be consulted for latest results. The reader should be aware that preliminary results are often specialized, technical presentations, and not until considerable work has been done will popular articles be available that will explain all of the implications resulting from intensive biomass harvest of special use to forest managers.

COASTAL PLAINS (SITES A, B, C)

Riekerk, H., B. F. Swindel, and J. A. Replogle. 1980. Effect of forestry practices in Florida watersheds. In Proceedings of Symposium on Watershed Management, July 21-23. Boise, ID. p. 706-720.

Riekerk, H., S. A. Jones, L. A. Morris, and D. A. Pratt. 1978. Hydrology and water quality of three small lower Coastal Plain forested Watersheds. Proc. Soil and Crop Sci. Soc. Fla. 38:105-111.

Riekerk, H., L. A. Morris, and C. I. Lassiter. 1979. The effect of harvesting of flatwoods forest on water quality and nutrient budgets. University of Florida, School of Forest Resources and Conservation. Resour. Rep. 6: 109-112.

Riekerk, H., L. F. Conde, J. C. Hendrickson, and W. S. Cain. 1981. Research on environmental and site effects of forest management practices in the Lower Coastal Plain. In Proceedings of the First Biennial Southern Silvicultural Research Conference, Atlanta, GA, Nov. 6-7, 1980. USDA Forest Serv. Gen. Tech. Rep. SO-34:331-338.

Gordon, Robert, J. H. Miller, and C. Brewer. 1981. Site preparation treatments and nutrient loss following complete harvest using the Nicholson-Koch Mobile Chipper. In Proceedings of the First Biennial Silvicultural Research Conference, Atlanta, GA, Nov. 6-7, 1980. USDA For. Serv. Gen. Tech. Rep. SO-34:79-84.

Koch, P., and T. E. Savage. 1980. Development of the swath felling mobile chipper. J. For. 78:17-21.

PIEDMONT (SITES D, E)

McMinn, James W., and Wade L. Nutter 1981. Energy wood harvesting--A study of pitfalls and promises. Georgia Forestry Commission, Ga. For. Res. Pap. 17. 6 p.

Nutter, Wade L., and James W. McMinn. 1981. Total-tree chipping: What about nutrient drain? In Proceedings of the Southeast Section Annual Meeting, Forest Products Research Society, Savannah, GA, Nov. 20, 1980: 3-7.

Kodoma, H. E., and D. H. Van Lear 1980. Prescribed burning and nutrient cycling relationships in young loblolly pine plantations. South. J. Appl. For. 4(3):118-121.

RIDGE AND VALLEY (SITE F)

VanHook, R. I., D. W. Johnson, D. C. West, and L. K. Mann. 1981. Environmental effects of harvesting forests for energy. For. Ecol. Manage. 4:79-94.

Mann, L. K. and D. C. West. 1981. Whole-tree harvesting: First year progress report--impacts on productivity and nutrient change. Oak Ridge National Laboratory ORNL/TM-7873. 35 p.

Mann, L. K., and D. C. West. 1981. Whole-tree harvesting: Second-year progress report--impacts on forest nutrients and carbon dynamics. Oak Ridge National Laboratory, ORNL/TM-7874. 90 p.

BLUE RIDGE (SITE G)

Waide, J. B., and W. T. Swank. 1976. Nutrient recycling and the stability of ecosystems: Implications for forest management in the Southeastern United States. In America's Renewable Resource Potential--1975: The Turning Point. Natl. Conv. Soc. Am. For. Proc. 1975:404-424.

Swank, W. T., and G. S. Henderson. 1976. Atmospheric input of some cations and anions to forest ecosystems in North Carolina and Tennessee. Water Resour. Res. 12:541-546.

Waide, J. B., and W. T. Swank. 1977. Simulation of potential effects of forest utilization on the nitrogen cycle in different southeastern ecosystems. In Watershed Research in Eastern North America: A Workshop to Compare Results. David L. Correll, ed. Vol. 2, Smithsonian Inst., Edgewater, MD. p. 767-789.

Swank, W. T., and J. B. Waide. 1980. Interpretation of nutrient cycling research in a management context: Evaluating potential effects of alternative management strategies on site productivity. In Forests: Fresh perspectivies from ecosystem analysis. R. H. Waring, ed. Oregon State Univ. Press, Corvallis, OR. 137-158.

Swank, W. T., and J. E. Douglass. 1977. Nutrient budgets for undisturbed and manipulated hardwood forest ecosystems in the mountains of North Carolina. In Watershed Research in Eastern North America: A Workshop to Compare Results. David L. Correll, ed. Vol 1. Smithsonian Inst., Edgewater, MD. p. 343-363.

REFERENCES CITED

1. Georgia Forestry Commission. 1979. Georgia's wood energy program. Ga. For. Comm., Macon, Ga. 80 p.
2. Nutter, Wade L. 1982. Comparison of nutrient loss resulting from wood energy harvest and conventional harvest, and site preparation methods. Ga. For. Res. Pap. (In preparation.)
3. U. S. Department of Agriculture, Forest Service. 1969. A forest atlas of the South. USDA For. Serv., South. and Southeast. For. Exp. Stns., New Orleans, La. and Asheville, N.C. 27 p.

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